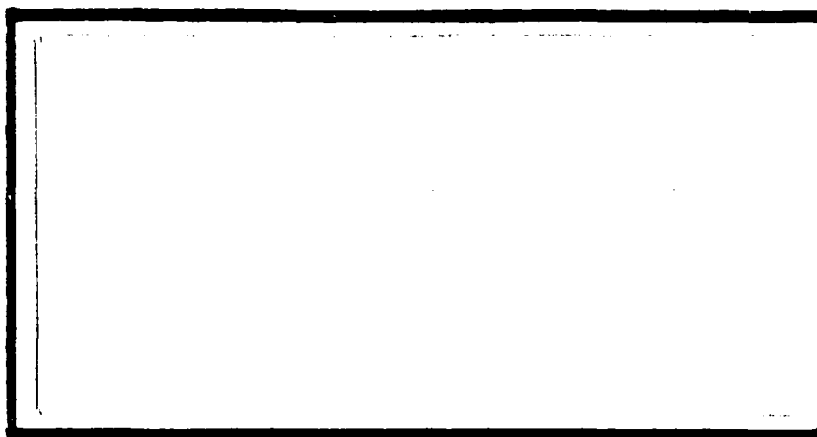
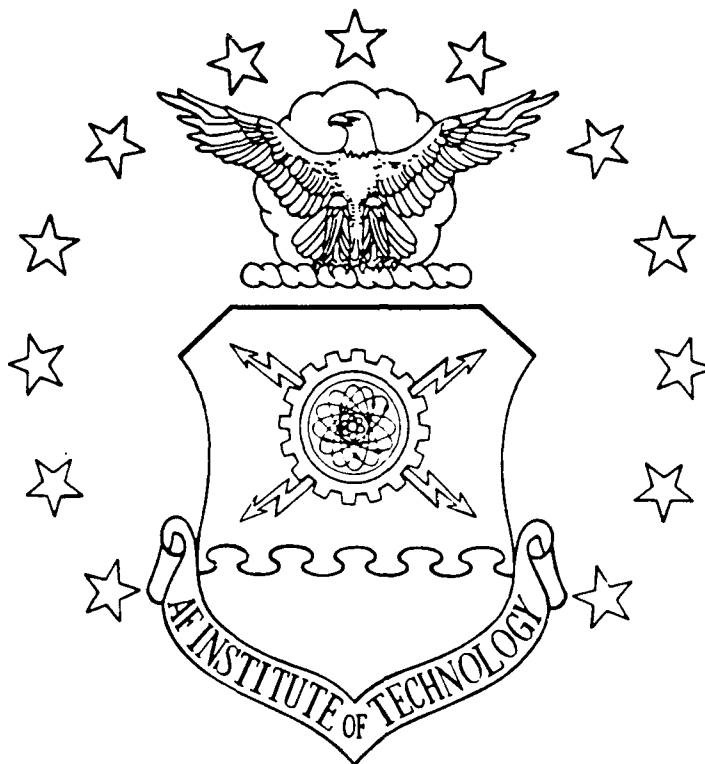


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INVESTIGATION OF A SAMPLING TECHNIQUE
FOR OBTAINING AIRFIELD PAVEMENT
CONDITION INDEX

THESIS

Richard M. Brubaker
Captain, USAF

AFIT/GEM/DEE/88S-2

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AFIT/GEM/DEE/88S-2

INVESTIGATION OF A SAMPLING TECHNIQUE FOR
OBTAINING AIRFIELD PAVEMENT CONDITION INDEX

THESIS

Presented to the Faculty of the School of Systems and
Logistics of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Engineering Management

Richard M. Brubaker

Captain, USAF

September 1988

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Richard M. Brubaker
Captain, USAF

Table of Contents

	Page
Acknowledgements	ii
List of Figures	v
List of Tables	vi
Abstract	vii
I. Introduction	1
General Issue	1
Problem Statement	5
Research Objectives	7
Research Questions	7
Scope	7
Assumptions	8
Limitations of the Study	9
Definitions	9
Availability of Data	10
II. Literature Review	11
Introduction	11
Pavement Distress Index	13
Pavement Management Systems	19
Comparison of Pavement Management Systems	25
Comparison of Pavement Evaluation Techniques	26
Summary	28
III. Methodology	29
Introduction	29
Survey Procedure	30
Population and Sample	31
Data Collection	32
Statistical Methods	33
Measuring Engineering Significance	34
IV. Analysis	37
Introduction	37
Deviation of the Sample PCI vs the True PCI	38
Confidence Level Using the Alternative Sampling Rate	38
Affect on Network Level Management	40
Summary	47

	Page
V. Summary, Conclusions, and Recommendations . .	49
Summary	49
Conclusions	50
Recommendations	53
Appendix A: PCI Report	56
Appendix B: Distress Data Report	57
Appendix C: Budget Planning Report	59
Appendix D: PCI Frequency Report 1988 and 1989 . .	61
Appendix E: Condition History	64
Appendix F: Inspection Schedule Report	65
Appendix G: Field Survey Data Form	67
Bibliography	68
Vita	71

List of Figures

Figure	Page
1. PCI Scale	16
2. Section T-36 Predicted PCI	42
3. Pavement Deterioration vs Time	47

List of Tables

Table	Page
1. Airfield Pavement Distress Types	3
2. Comparison of Pavement Management Systems . . .	27
3. Comparison of Pavement Evaluation Techniques .	27
4. PCC Pavement Rehabilitation Costs in \$/Sq Ft .	36
5. Mean PCI Absolute Deviation	39
6. Comparison of Budget Planning Reports 100 Percent Survey vs AE Survey Rate (Section PCI deviations of more than 5 points)	44
7. Comparison of Budget Planning Reports 100 Percent Survey vs AE Survey Rate	45
8. Recommended Order of Precedence for Prioritization (Poor Pavement Rehabilitated First)	48
9. Comparison of Maintenance and Repair Prioritization Using Predicted 1989 PCI	48
10. Recommended Sampling Rate	54

Abstract

For the past several years Air Force bases have been implementing the PAVER pavement management system. In the performance of the initial pavement condition survey, eight bases used a sampling technique the Air Force Engineering and Services Center (AFESC/DEMP) believes may have provided erroneous data on existing airfield pavement conditions.

The purpose of this study is to investigate and quantify the accuracy of the pavement condition data obtained sampling 10 to 20 percent of the airfield pavement section based on the judgement of the pavement engineer. In order to solve the primary research objective, three research questions are answered. (1) Is the mean Pavement Condition Index (PCI) using this sampling technique significantly different than the true PCI determined by surveying 100 percent of the airfield pavement section? (2) Is the PCI obtained using this sampling technique more representative of the section's condition than random sampling would achieve? (3) Does this sampling technique adversely affect the ability of an engineer to manage airfield pavements at the network level?

To answer the research questions, all of the sample units in thirteen sections at five Air Force bases are surveyed. All of these bases were previously surveyed

according to the sampling technique in question. The 100 percent survey PCI and the sampling technique PCI for each section are compared.

The research finds that the sampling technique and the sampling rate in question provide an accurate PCI for network level analysis of airfield pavements. The analysis indicates the lower sampling rate provides a PCI almost as accurate as 100 percent sampling. In addition, the sampling technique selected samples units that are more representative of the pavement section condition than random sampling at the same sampling rate. Finally, the investigation determined that this sampling technique provides the engineer with reliable data about the condition of the airfield pavements. This, in turn, gives the engineer confidence that his network level management strategies are appropriate.

This study covered only one type of airfield pavement, portland cement concrete (PCC). Therefore, this study cannot be generalized across other types of pavement surfaces such as asphalt. It is recommended that similar studies be performed on these other airfield surfaces to determine the applicability of this survey technique for conducting airfield condition surveys. In addition, each base that contracts out the implementation of PAVER should inspect the work of the agency using this sampling method.

INVESTIGATION OF A SAMPLING TECHNIQUE FOR OBTAINING AIRFIELD PAVEMENT CONDITION INDEX

I. Introduction

General Issue

The Air Force has over 247 million square yards of airfield pavements which it must maintain. This is equivalent to a ten lane highway from Maine to California (15:1). Over 70 percent of these airfield pavements were built prior to 1960 (8:1). Nearing the close of the 1980s many of these pavements have reached the end of their design service lives. This in turn has resulted in steadily increased maintenance costs in order to keep these pavements in service. "Approximately 52.7 million dollars were spent on maintenance and repair work for Air Force airfield pavements worldwide in 1981, as compared to 36.3 million dollars in 1977" (8:1). The Air Force, realizing that this trend would continue, wanted to ensure that its pavement maintenance funds were used efficiently and effectively. Therefore, the Air Force contracted with the U.S. Army Construction Engineering Research Laboratory (CERL) to develop a pavement maintenance management system.

The research program involved the development and validation of a practical pavement condition survey and evaluation procedure that relates to maintenance needs and priorities. The resulting procedure includes a newly developed Pavement Condition Index (PCI) (19:381).

The PCI is a nondestructive pavement evaluation technique that uses pavement distresses to determine the structural integrity and operational condition of the pavement. Distresses are defects that appear on the surface of the pavement such as cracks and potholes. There are 31 different types of pavement distresses for airfield pavements. A listing of the different types is given in Table 1. Fifteen of these describe distresses in rigid portland cement concrete pavement and the remaining characterize distresses in flexible (asphalt concrete) pavement (5:3-8). Although there are 31 pavement distress types, there are three characteristics of pavement distress that play a major role in the determination of the PCI:

- (1) Type of distress
- (2) Severity of distress (low, medium, or high defined by width of crack, spalling, debris present, etc.)
- (3) Density of distress (percentage occurrence in pavement area surveyed) (19:382).

The pavement condition survey developed by CERL uses a stratified random sampling technique to determine the pavement condition of each section in a network (23:24). A stratified random sample is a random sample in which the population is divided into two or more strata. A random sample is then drawn from each stratum. The Air Force has incorporated this sampling technique in the regulation concerning its Airfield Pavement Evaluation Program, Air Force Regulation AFR 93-5.

TABLE 1

Airfield Pavement Distress Types (5:3-7)

<u>Rigid Pavement</u>	<u>Flexible Pavement</u>
1. Blow-up	1. Alligator cracking
2. Corner break	2. Bleeding
3. Longitudinal/transverse/ diagonal crack	3. Block cracking
4. "D" crack	4. Corrugation
5. Joint seal damage	5. Depression
6. Patching $\leq 5 \text{ ft}^2$	6. Jet blast
7. Patching/utility cut $> 5 \text{ ft}^2$	7. Joint reflection
8. Popouts	8. Longitudinal and transverse cracking
9. Pumping	9. Oil spillage
10. Scaling/map	10. Patching
11. Settlement/fault	11. Polished aggregate
12. Shattered slab	12. Raveling/weathering
13. Shrinkage crack	13. Rutting
14. Spalling-joints	14. Shoving from PCC
15. Spalling-corner	15. Slippage cracking
	16. Swell

The sampling method in AFR 93-5 uses a 95 percent confidence level to determine the total number of samples to be surveyed in a section. "A confidence level is the probability that the value obtained is within the interval of plausible values for the parameter being estimated" (7:250). In this case, the parameter is the average PCI of an airfield pavement section. In addition, AFR 93-5 states: "Samples must be selected randomly, to ensure an unbiased result" (5:3-3).

Once the condition of the pavement has been determined through the PCI this information can then be used in the PAVER pavement management system (PMS) to assist the engineer in managing the airfield pavements. PAVER is a

computerized PMS designed by CERL which provides the engineer with a practical decision-making procedure for identifying cost-effective maintenance and repair for airfields. In addition, PAVER has other important capabilities. These include data storage and retrieval, inspection scheduling, pavement condition history, and determination of present and future pavement condition (21:151).

A number of Air Force bases have hired Architectural and Engineering (AE) firms to conduct pavement condition surveys of their airfield pavements. The sampling technique outlined in the AE Statement of Work (SOW) for George AFB conflicts with the sampling method in AFR 93-5. The SOW states:

The pavement inspection for airfields shall be done in accordance with AFR 93-5 except that the sampling rate shall be as outlined in section 3.3 below.

3.3 SAMPLE UNIT INSPECTION RATE: Determine the number of random sample units to be inspected based on the total number of sample units in the section as follows:

<u>No. of Sample Units in Section</u>	<u>Minimum No. of Units to be Inspected</u>
1-4	1
5-10	2
11-20	3
21-40	4
Over 40	10% rounded up

3.4 SELECTION OF SAMPLE UNITS:

Random sample units shall be representative of the overall section condition based on engineering judgement (9:Ch 3,1).

The Air Force Engineering and Services Center (AFESC/DEMP) is concerned that this alternative sampling technique used by the AE firms is not providing an accurate assessment of airfield pavement conditions. This, in turn, may be degrading the pavement management of the bases that hire AE firms to conduct their pavement condition surveys. Conversely, if the alternative sampling technique is adequate, it will save the Air Force both money and time in implementing PAVER. For instance if an architectural engineering firm were to perform a PCI survey on a 100 section airfield according to AFR 93-5 the cost of the survey would be approximately \$24,000 and would take 370 manhours (3). The cost and time to perform the same survey using the AE sampling technique would be \$6500 and 100 manhours, respectively.

Mr. Stuart Millard, a pavement engineer at the AFESC, believes that the random sampling method outlined in AFR 93-5 is the best method for obtaining an accurate airfield pavement condition survey (16). He believes this because the method allows one to be 95 percent confident that he is within plus or minus 5 points of the true condition index of the pavement.

Problem Statement

The pavement condition survey results in the computation of a Pavement Condition Index (PCI) number which ranges from a low of 0 to a high of 100. The PCI provides:

- 1) a standard measure of pavement condition in terms of both structural integrity and surface operational condition,
- 2) an objective and rational basis for determining maintenance and repair needs and priorities, and
- 3) a warning system for early identification of major repair requirements (19:381).

In order for the Air Force's pavement maintenance management system to work, the pavement condition survey must provide an accurate PCI. This is accomplished by calculating the average PCI from a representative sample of each section. A representative sample is typical of the entire section.

If the sample taken in a section is not representative, the average PCI for that section will be in error. This, in turn, will cause the pavement engineer to improperly identify and prioritize maintenance and repair requirements. Work will be performed in areas where it is not cost effective while neglecting those areas that could maximize the use of limited maintenance and repair dollars. In addition, pavement sections that need repair today may not be identified for a number of years. This delay will result in increased pavement deterioration and repair costs for these sections. For an Air Force base to have an effective pavement maintenance management system, an accurate PCI must be obtained at a reasonable cost. An accurate PCI is one that is useful to the pavement engineer in determining when it is most cost effective to accomplish maintenance and repair on each pavement section at his base.

Research Objectives

The objective of this research is to determine if the sampling method outlined in the AE Statement of Work provides an accurate PCI, as defined above. This includes determining if there is a significant difference between the true PCI and the AE sampled PCI, and quantifying that difference.

Research Questions

To accomplish the research objective, the following questions are answered:

1. Is the absolute deviation between the average PCI obtained from the sampling method used in the AE Statement of Work and the true average PCI for a section significant?
2. What level of confidence is obtained randomly selecting samples with the sampling rate in the AE SOW using the error interval given in AFR 93-5 of plus or minus 5 points?
3. Does the AE sampling rate adversely affect the pavement engineer's ability to correctly determine, at the network level, pavement section maintenance and repair priorities and maintenance and repair costs for airfield pavements?

Scope

This research is limited to Air Force bases within the continental United States (CONUS) that have implemented

PAVER and possess portland cement concrete airfield pavements. Although other Air Force bases outside the CONUS may use the same criteria for determining airfield pavement conditions, time and cost considerations precluded using these bases in the research. Research is further limited to five of the eight bases that have conducted pavement condition surveys using the sampling technique outlined in the George AFB SOW. The time involved in performing the surveys and the limited available TDY funds preclude surveying all eight bases. The five participating bases are: Tyndall, Grissom, Whiteman, Little Rock, and Langley Air Force Bases.

Assumptions

The research is based on the following assumptions:

1. Significant differences in the sampling method can be quantified through the use of descriptive statistics.
2. The representativeness of the sampling technique under investigation can be analyzed through the use of inferential statistics.
3. Differences in the sampling methods that have engineering significance can be quantified using several network level management reports from PAVER.
4. One hundred percent survey data can be used in the PAVER program's budget report to calculate the actual cost to repair a pavement section.

Limitations of the Study

This research focuses on one type of airfield pavement, portland cement concrete pavement. Therefore, any conclusions drawn from this study cannot be generalized across other pavement types. In addition, only taxiway and aprons are surveyed because of the difficulty in obtaining clearance from bases to survey active runways. Consequently, conclusions derived from this research will not include runways.

Definitions

The following key terms are used in this research:

Network Level Analysis -- The analysis activity associated with the total pavement network. The most important step in accurately analyzing network needs is projecting the future condition of each section in the network. This projection provides the input needed to identify sections requiring major M&R in the future (22:6).

Pavement Section -- "Pavement having consistent structural thickness and materials, constructed at the same time, and receives the same traffic" (20:83).

Pavement Condition Index (PCI) -- An objective measurement of pavement deterioration, manifested by pavement distress.

Pavement Condition Rating (PCR) -- A numerical value given to a subjective rating of the pavement condition of a sample unit such as "excellent," "good," "fair."

Deduct Value -- A numerical value equal to 100 minus the average PCR for a sample unit given by three experienced engineers who independently rated each sample unit

Availability of Data

As was mentioned previously, there are eight Air Force bases that had pavement condition surveys completed using the sampling technique in question. These bases provide an adequate data base for conducting research. Chapter III of this proposal provides additional information on how the data bases are used to answer the research questions and the statistical assumptions made.

II. Literature Review

Introduction

In the previous chapter an understanding of what the PCI is and how it is determined was developed. The PCI, or any pavement condition rating, is an important tool in pavement management systems for evaluating pavement requirements. The reason is because the condition index is related to pavement performance. Performance is defined as the pavement's ability or inability to support traffic, due to surface distress or roughness, over time (4). As a pavement's performance declines, the condition index decreases. This complementary characteristic of the condition index and pavement performance makes both necessary for evaluating a pavement's requirements (10:97-98). However, field experience has shown that an objective measurement of the pavement's condition, such as the condition index, is invaluable for predicting a pavement's future performance (19:382).

An effective pavement management system (PMS) is the primary reason for having a condition index. Although there is no universally accepted definition of a PMS, most of the literature agrees that it is a type of management information system. It is used to assist in making decisions about the pavement network. A pavement management system identifies those sections that need maintenance and repair and the optimum time for performing them.

A PMS symposium paper provided one of the most thorough definitions found in the literature;

A pavement management system (PMS) is a tool that provides decision-makers at all management levels with optimum strategies derived through clearly established rational procedures. A PMS evaluates alternative strategies over a specified analysis period on the basis of predicted values of quantifiable pavement attributes, subject to predetermined criteria and constraints. It involves an integrated, coordinated treatment of all areas of pavement management, and it is a dynamic process that incorporates feedback regarding the various attributes, criteria, and constraints involved in the optimization procedure (18:7).

Therefore at the network level the essential requirements of a PMS are:

1. Capability of easily being updated and or modified as new information and better models become available.
2. Capability of considering alternative strategies (e.g., do no work, fix the most deteriorated pavement first, or fix less deteriorated pavement first).
3. Capability of basing decisions on rational procedures that use quantifiable measurements, constraints and characteristics.
4. Capability of using feedback to highlight the consequences of decisions (18:9).

All pavement management systems (PMS) provide one or more of the essential requirements described above. They range from simple pavement data inventory systems to complex decision support systems. All of the systems use some form of a condition index to evaluate the present condition and/or performance of the pavement. The literature search indicates there are a number of condition indexes and their associated pavement management systems' being used today.

Pavement Distress Index

An integral part of any pavement management system is the pavement rating that is calculated from field measurements of various parameters. It is from these measurements that a final condition of the pavement section is determined. All of the PMSSs that were reviewed incorporate a condition index into network level analysis. The literature further reveals that there are two principal condition indexes in use today, Pavement Condition Index (PCI) and Present Serviceability Index (PSI). These two will be discussed in detail in this section. Other condition indexes available are slight modifications of the PCI and PSI.

Pavement Condition Index (PCI). The PCI is a composite index of structural integrity and operational condition of a pavement section (21:152). The PCI uses only a visual survey of the distresses in the pavement section to determine a condition index for routine evaluations. The reason for this is the cost involved in measuring the other parameters of pavement performance; roughness, skid resistance and hydroplaning (19:382). In addition, empirical evidence has shown that pavement distresses can be indirectly related to the parameters of pavement performance.

An objective measurement and consideration of pavement deterioration (manifested by pavement distress) provides a valuable index relating to indirect measurements of localized roughness, load carrying capacity, and, in some respects, skid resistance/hydroplaning potential (19:382).

There are three characteristics of pavement distress that go into calculating the PCI. They are: (1) type of distress; (2) severity of distress (low, medium, or high); and (3) density of distress (percentage occurrence in pavement area surveyed) (19:382). This index is based on the summation of deduct values over an entire pavement section. How large the deduct value is depends on the type of distress, its severity, and its percent occurrence in the section. Load induced distresses have larger deduct values than non-load induced distresses, such as environmental related distresses. Since the distress type has a major influence on the PCI, it was important that accurate distress definitions that represent field conditions be developed (19:383).

During the development of the PCI, over 30 different distress types were identified, 15 for asphalt concrete and 16 for portland cement concrete. Standardized distress definitions and deduct values were developed to make computing the PCI more objective. This was done so that a less experienced engineer would calculate the same PCI as an experienced pavement engineer, plus or minus 5 points. The distress definitions and deduct values are based on the collective judgement of experienced pavement engineers (21:152).

The initial deduct values were determined in the following manner:

1. Three experienced engineers independently rated sample units of 20 slabs each. Each rater gave the sample unit a subjective rating according to the scale in Figure 1 such as "excellent," "good," or "fair" and a numerical value within that rating. This rating is defined as the pavement condition rating (PCR).
2. The ratings were made for four to five levels of density for each distress at a given severity level.
3. The mean of the three subjective ratings (PCR) from the experienced engineers was computed for each density level, and the mean deduct value (DV) was computed as:

$$DV = 100 - PCR$$

A plot of density of distress versus mean deduct value was developed, and a best fit smooth curve was fit through the points (19:384).

The initial deduct values are based on the average subjective rating (PCR) of the pavement condition by three experienced engineers for each distress type. This PCR value is then subtracted from 100 to obtain the deduct value. A plot of the density of the distress occurring in the sample unit versus the mean deduct value provides a best fit smooth curve. This curve allows the engineer to properly determine the deduct value for any distress type and density encountered. These distress definitions and deduct values were then tested, revised, improved, and validated over several years (19:383).

Another important aspect of any pavement evaluation procedure is how much of the pavement network needs to be tested or inspected for network level analysis. This is important because the more inspection that must be done the more costly the procedure and the pavement management system.

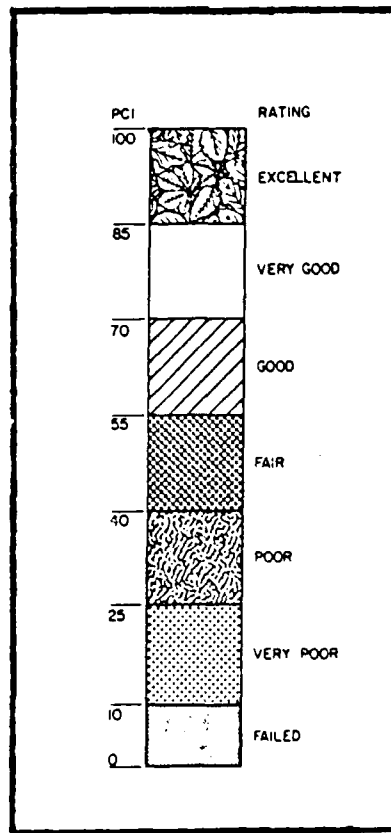


Figure 1. PCI Scale (5:A1-2)

The accepted Air Force method for the PCI, according to AFR 93-5, is a random sampling to achieve 95 percent confidence based on the standard deviation and the total number of sample units in the section. Generally, the number of sample units surveyed is less than 80 percent. However, many agencies use the AE sampling technique which involves surveying between 10 and 20 percent of the section (23:24). In addition, the sample units to be surveyed are based on the engineering judgement of the pavement engineer. This AE sampling technique, used at several Air Force bases and the subject of this research, was discussed in detail in Chapter I.

Present Serviceability Index (PSI). The PSI is an equation of the physical measurements such as roughness or skid resistance of a large number of pavement sections formulated to predict the Present Serviceability Rating (PSR) of those pavements (1:42). The PSR is the subjective average rating of the pavement sections by a panel of road users.

Since the PSR is a subjective rating of the riding quality of the pavement, it is heavily influenced by the roughness of the road. "Studies made at the American Association of State Highway Officials (AASHO) Road Test have shown that about 95 percent of the information about the serviceability of a pavement is contributed by the roughness of its surface profile" (10:62). Therefore, the PSI is more closely correlated with the roughness of the pavement than any other measure of pavement condition. In addition, roughness is also correlated with performance. The rougher the pavement the poorer the perceived performance by the road user.

The equation for the PSI was developed in a study conducted in 1958 and 1959 (1:48). That equation is given below:

$$PSI = 5.41 - 1.80 \log(1+SV) - 0.09 \sqrt{C + P}$$

where

SV = mean slope variance in wheel path ($\times 10^6$)
C = Cracking ($\text{ft}/1000 \text{ ft}^2$)
P = Patching ($\text{ft}^2/1000 \text{ ft}^2$)

The PSI then becomes a mechanical or physical measurement of the pavement condition, usually roughness, that correlates with the Present Serviceability Rating (PSR).

Roughness measurements are taken mechanically using an Automated Roughness Analyzer (ARAN) or physically by measuring the rutting depth of a pavement section. These measurements are then used to calculate the PSI of the pavement section. The PSI is then used as a measure of the PSR. "The PSI is not a number that can be used directly to represent the performance of a pavement. It is intended to predict PSR to a satisfactory approximation" (10:78). In other words the PSI is an objective measure of the pavement condition which is subjectively determined by a panel of road users.

With the serviceability index the pavement serviceability rating for any section in the network can then be estimated. The literature review indicated the PSI is determined using a 100 percent sampling of the pavement section (1,10,13).

Other Pavement Distress Indexes. The Pavement Rating Score (PRS) from Arvada, Colorado's pavement management system (2:36-43) is a hybrid of both the PCI and PSI indexes discussed earlier. Idaho's Pavement performance index is also modeled after both the PCI and PSI indexes but with one significant difference, Idaho's index includes a structural index portion. The structural index for a pavement section is calculated using a minimum of three static load deflection tests (13:45).

Except for the structural index portion of Idaho's pavement performance index both Arvada's and Idaho's indexes require 100 percent of the section being surveyed for network level analysis (2,13).

Pavement Management Systems

In order to gain a better understanding of how the condition index is used at the network level, it is necessary to look at existing pavement management systems (PMS) to see how they assist in network level analysis. In this section of the chapter, three of the most comprehensive existing systems will be described including the Air Force's PMS PAVER.

PAVER Pavement Management System. The Air Force's choice of pavement management systems since 1984 has been PAVER. It was developed by the U.S. Army Construction Engineering and Research Laboratory (CERL) for the Air Force and other Department of Defense (DOD) agencies such as the Army and the Navy. PAVER is a comprehensive PMS that can help manage pavements at both the project and network level. Since network level analysis is the focus of this study, only PAVER's capabilities in this area will be addressed. The PAVER system has most of the features required in a pavement management system as outlined previously.

Two significant features of PAVER are its relatively low cost, to comparable systems, and its simplicity in maintaining and updating the system data base (25:42). These features are important to the Air Force because of

funding limitations and the relative inexperience of Air Force personnel. But it is the PMS's ability to help manage the airfield pavements at the network level that is important to the pavement engineer.

PAVER can generate a number of reports that can assist the engineer in managing the airfield pavements.

1. PCI Report - sorts the inspection data in such a way to provide the engineer with the current PCI value for each section within the pavement network (Appendix A). This allows the engineer to see at a glance which sections in the network are going to need major repair versus those needing routine maintenance.

2. Distress Data Report - gives a breakout of distress types, their percentages, and the percentages of distress attributed to load and climate within each pavement section of the network (Appendix B). The pavement engineer can then use this data to determine an appropriate maintenance and repair strategy.

PAVER not only provides reports detailing the condition of any pavement section but can also assist the pavement engineer in determining the long term budget requirements of the entire network. Initiating a budget for the maintenance and repair of the pavement network is an important management step for the engineer (25:48).

3. Budget Plan BUDPLAN Report - provides a 5 year budget plan for the pavement network. This report details

the amount of money needed in order to keep the pavement network at a given condition level (Appendix C). The engineer inputs the minimum PCI level that is acceptable for various combinations of pavement sections. In addition, the engineer inputs estimated repair costs including inflation rates for various surface types and PCI levels (22:9). These costs are based on the assumption that that repair will result in a pavement section PCI of 100.

4. Frequency (FREQ) Report - indicates the future condition of the pavement network, either graphically or in a listing, based on a straight line extrapolation of the last two PCI surveys (Appendix D). This information can then be used by top management to determine the future consequences of the budget decisions they make.

5. Condition History Report - shows in a graph the past performance of each pavement section (Appendix E) (22:10). If the pavement engineer knows the condition history of a pavement section, he can do a better job of determining when and how that section should be repaired or replaced.

Another important management consideration is how often to schedule inspections. If inspections are scheduled too often, both engineer's time and money are wasted. If inspections are not scheduled often enough, the pavement network could deteriorate to the point where expensive replacement is the only alternative.

6. Inspection Frequency Report - provides the engineer a possible inspection schedule of the pavement network. A pavement section's inspection frequency is based upon its deterioration rate (drop in PCI per year). A pavement section may also be identified for inspection when the predicted PCI drops below a predetermined minimum. A plot of the pavement sections that would need inspection over the next 6 years is produced (Appendix F) (22:9).

PAVER provides the pavement engineer a structured pavement management system which can improve management of the pavement network. However, PAVER is not the only PMS that has been developed.

Arvada, Colorado: Pavement Management System. The Arvada PMS is a computerized system that differs from PAVER in two areas. First, the Arvada PMS was developed only for network level management and does not have the capability for project level management (2:36). Second, the Arvada system does not have the capacity to predict the future condition of the pavement network through its pavement rating index. The system is similar to PAVER in its main objective: determination of present conditions and the estimation of rehabilitation needs and costs at the network level (2:36).

This objective is realized through a variety of reports that the computer program provides. There are nine such reports that assist the pavement engineer in managing the

city street network. Four contain street descriptions and condition survey information which is similar to pavement definition portion of the PAVER program. Two reports provide information on the condition of curbs, gutters, sidewalks, etc. These six reports will not be discussed further here. The other three deal directly with network level management of a street system.

In one report, a listing of the condition survey rating score for the pavement network is given. It is sorted by street classification and then by rating score from worst to best in street sequence (2:38). This information is similar to what the PCI Report in PAVER provides. The streets are classified as either principal or minor, arterial or collector, or local.

Using the condition survey rating score list, the Arvada PMS can assist the engineer in determining the rehabilitation priorities and preventive maintenance needs of the pavement network. It does this through the Rehabilitation Recommendation report. This report groups the pavement network first by street classification and rehabilitation priorities and the by type of recommended rehabilitation (2:38).

The recommended rehabilitation activity for a particular pavement section is based "on the type, extent, and severity of the existing distresses present and the amount of traffic carried by the facility" (2:39).

The prioritization of the recommended rehabilitation projects is unique to the Arvada pavement management system (PMS). These priorities are computed using a mathematical equation.

It is based on the cost of the specific rehabilitation alternative, length of pavement to be rehabilitated, average daily traffic, and the pavement condition rating score (2:41).

The equation contains factors for estimated repair cost, pavement section size, type of traffic (industrial or residential), and the pavement condition rating score.

The last report generated by the Arvada PMS is a ride quality report. It rates all of the streets for ride quality from worst to best based on the subjective assessment of the surveyor. This report provides an indication of which pavement sections may need rehabilitation.

Idaho's Pavement Management System. The Idaho system is known as a Pavement Performance Management Information System (PPMIS). The PPMIS was designed to assist state of Idaho personnel in managing 612 miles of interstate highways plus about 5000 miles of state highways (13:43).

This computerized pavement management system uses two programs to assist in network level analysis. The first sorts and summarizes the information gathered in field surveys of the pavement network. It also provides a printed report of each pavement section (13:44).

After the field data has been sorted and summarized, the output is then used as input for a program which lists the pavement sections in ascending order of various index parameters. These parameters include deflection, visual condition, and roughness measurements.

This program transforms the summarized measurements into indices [i.e., structural adequacy, present serviceability (PSI), and distress indices]. These various indices are combined into a final, overall index value for each section (13:44).

The program then uses these measurements to compute the structural, serviceability and distress indexes which are combined into a final index for each section. The report provided by this program lists the pavement sections in ascending order according to the final index.

This report can then be used by the engineer as a first step in prioritizing the rehabilitation and maintenance needs of the pavement network. It also can assist the engineer, through the various index parameters, in determining the appropriate rehabilitation strategies for the pavement network.

Comparison of Pavement Management Systems

There are numerous examples in the literature of different pavement management systems in use today. Most were specially developed or modified for that state, province or local district's unique situation. All of them meet some or most of the requirements that define a pavement

management system, which were outlined at the beginning of the chapter. Table 2 displays how many of these requirements are fulfilled by each of the PMS's discussed in this report. As the table indicates, PAVER is a very comprehensive system that can assist the engineer in network level management of the pavement network. It also has the capability to be implemented at any location worldwide. This is especially important to the Air Force since it has air bases in many parts of the world.

Comparison of Pavement Evaluation Techniques

One of the most important aspects of any pavement management system is the method used to evaluate a pavement's past performance or present condition. The literature indicates that there is no universally accepted evaluation technique for pavement performance. In fact, every PMS reviewed performed this aspect of pavement management differently. Table 3 displays how each of the pavement evaluation techniques are conducted including survey sampling rate requirements. As the table shows, the literature review revealed that only the PCI can be used for both airfields and streets. In addition, the PCI is the only pavement evaluation technique that uses visual inspections exclusively. Finally, it was the only procedure requiring less than 100 percent sampling of the pavement network.

TABLE 2

Comparison of Pavement Management Systems

Requirements	Pavement Management System		
	PAVER	Arvada PMS	PPMIS
Easily updated or modified	X	X	X
Considers alternative strategies.	X		
Decisions based on rational procedure with quantified criteria.	X	X	X
Feedback on consequences of decisions.	X		

TABLE 3

Comparison of Pavement Evaluation Techniques

Parameter Measured	Pavement Evaluation Technique			
	PCI	PSI	PRS	Idaho's Index
Visual distress survey	X	X	X	X
Roughness measured mechanically	NA	X	NA	X
Pavement Deflection	NA	NA	NA	X
Sampling rate	< 80%	100%	100%	100%

X indicates the system meets this requirement or the evaluation technique measure this parameter.

NA indicates the evaluation technique does not measure this parameter to determine pavement condition.

Research has shown that for roads and parking lots a 10 to 20 percent sampling based on engineering judgement is sufficient for determining the PCI at the network level (26:19). However, as pointed out by Haas and Hudson, airport pavements present several problems in the area of performance or condition evaluation. These include:

1. The range of aircraft types presents a much wider variation of pavement-vehicle interaction than that which occurs on roads.
2. The effects of airport pavement roughness are related primarily to the safety and undercarriage damage as contrasted to roads where they are related to variations in quality of ride provided to the user (10:84).

Summary

PAVER is a comprehensive pavement management system which can be used to manage both airfield and street pavement networks. A network can consist of any pavement type: portland cement concrete (PCC), asphalt, or a combination of PCC and asphalt. The PCI associated with PAVAR is a low cost and effective evaluation technique to determine a pavement section's present condition and predict future condition. The literature revealed that the PCI pavement evaluation technique is the only one that has been tested and validated for airfields. However, there is no documentation to indicate whether the lower sampling rate for roads and streets is applicable to airfields. Chapter IV analyzes the data that will answer this question. Chapter III outlines the methodology for gathering and analyzing this data.

III. Methodology

Introduction

In order to answer the research questions and complete the research objective, a descriptive statistical operation is performed on the AE sampling technique for surveying airfield pavement conditions. An analysis of this descriptive method determines if there is a significant difference in the average PCI calculated using this sampling technique and the true average PCI (population parameter) for a section of pavement. A significant difference is defined as the sample average PCI deviating more than 5 points from the true average PCI in a pavement section. This plus or minus 5 points is the maximum error interval allowed in AFR 93-5 in determining the PCI of a pavement section. If the results of the analysis of the descriptive statistical operation indicates a significant difference, then further research will determine if that difference is of engineering significance. This is accomplished by comparing the priorities and estimated maintenance and repair costs developed from the true average PCI and the PCI from the AE sampling technique. Maintenance and repair costs and priorities that are appreciably different indicate an engineering significant difference. In addition, an inferential statistical method determines if the AE sample technique PCI is more representative of the pavement section

condition, than random sampling. This analysis involves calculating the confidence level achieved taking a random sample from each section using the AE sampling technique and an error interval of plus or minus 5 points.

This research uses only primary sources. Primary data is preferred because the researcher is ultimately responsible for collecting it. This ensures the data is collected in the manner prescribed for in the study.

Survey Procedure

The survey procedure used in this study is outlined in AFR 93-5. This method for determining the PCI of a pavement section is an eight step process:

1. Divide the pavement section into sample units, normally there are about 20 slabs (generally 20 to 25 foot square slabs) per sample unit. In this research, all of the sections surveyed were already divided in this manner.
2. Visually inspect the sample units to determine distress types, severity levels, and density using the field survey data form (Appendix G).
3. For each distress type, severity level and density noted in the sample unit determine the deduct value from the distress type curve.
4. Compute the total deduct value (DV) for each sample unit by adding all deduct values for each distress type observed.
5. Determine the corrected deduct value (CDV) for the pavement section. The CDV is the TDV adjusted for the number of distress types with deduct values greater than five.
6. Calculate the PCI for each sample unit:

$$PCI = 100 - CDV$$

7. Compute the PCI for a pavement section by averaging the PCIs for all of the sample units surveyed in the section.
8. Determine the pavement condition rating from Figure 1.

In step 5, the CDV came about as a result of the initial field testing which found a significant deviation between the calculated PCI and the pavement condition rating (PCR) of experienced engineers.

This was especially true when more than one distress type and severity level combination existed in a section. Further analysis concluded that since the deduct value curves were derived for only one distress type, these deduct values cannot be added together when more than one distress type occurs in a pavement section (19:384).

Therefore, to better predict the PCR, a correction factor must be added to the PCI whenever more than one distress type is identified in a section.

The pavement evaluation procedure just described received extensive field testing at two Air Force bases prior to its being incorporated in the regulation. The results of the field tests indicated that nearly all of the distresses observed at the two Air Force Bases were adequately defined by the existing definitions. In addition, the calculated PCI values corresponded closely with the PCR for each section.

Population and Sample

the population of interest are those Air Force bases that had airfield pavement condition surveys accomplished using the sampling technique outlined in Chapter I. At the time of this research there are eight such bases, five of the eight are included in this study.

Data Collection

As stated previously, only primary data is collected for this research. Pavement condition surveys are conducted at the five bases included in this research. These surveys are accomplished according to the survey procedure outlined in AFR 93-5 Airfield Pavement Condition Evaluation Program, Chapter 3 except that a 100 percent survey sample will be taken. The 100 percent survey sample is required to determine the true average PCI of the pavement section. A sample of less than 100 percent only gives an estimate of the true average PCI of the section.

The 100 percent survey data is also used to calculate the AE sampling technique PCI for each section. This is accomplished by computing the average PCI from the sample units inspected by the AE in each section, using the data from the 100 percent survey. Calculating the AE sampling technique PCI in this way takes into account any decrease in the PCI that has occurred since the AE survey.

The resulting PCI values from all of the surveys are considered interval level data. As an illustrative example:

The difference between scale values of 56 and 59 represents the same quantity as the difference between the values of 114 and 117--the difference of 3 units having the same meaning regardless of where along the scale it occurs. Because of this property it is considered a metric scale and variables measured by it are considered quantitative variables (12:16).

Therefore, quantitative analysis of the data can be performed and conclusions drawn from this analysis.

Statistical Methods

The resulting data from the primary data collection is analyzed using both descriptive and inferential statistics. The descriptive statistical method used is the absolute deviation of the sample PCI and the true PCI.

This approach is required because the method of sampling under investigation is not random. The sample units inspected are judged to be the most representative sample units from each section based on the experience and expertise of the surveyor. Therefore, any inferential analysis of such a sample is not appropriate because the sample is not randomly taken. By a random sample we mean that every member of the population has an equal chance of being included in the sample; more strictly, every possible sample of the specified size has an equal chance of being selected from the population (12:9). This clearly is not the case with the sampling technique in question. Since a 100 percent sampling of each section is accomplished and this is the population of the section, descriptive statistical methods are applicable. A pavement section can be considered a population because it is a well defined collection of pavement characteristics.

A section has certain consistent characteristics throughout its area or length. These characteristics are structural composition (thickness and materials), construction history, traffic, and pavement condition (23:10).

The absolute difference of the population and sample PCI represents the variability that the sample PCI has from the

true PCI. Therefore, a variation of more than 5 points indicates a significant difference between the sample and true PCI's. The 5 point variation is based on the maximum error interval that a sample average PCI can have with the true PCI according to AFR 93-5.

Inferential statistics are used to determine how representative the AE sampling technique is of the section population. The AE sample size and known (population) variance are used to calculate the confidence level that results in an error interval of 5. Again this error interval is the maximum allowed in AFR 93-5. The confidence level calculated shows the probability of randomly selecting a sample using the AE sampling rate and coming within plus or minus 5 points of the true average PCI. A low confidence level along with a small absolute PCI deviation for a section indicates the AE sampling technique is more representative of the section condition than random sampling can achieve. Whereas a high confidence level along with a large absolute PCI deviation indicates random sampling to be more representative.

Measuring Engineering Significance

To test for an engineering significant difference, it is necessary to compare the results of management activities done at the network level using the above mentioned PCIs. In this research both the budget planning report BUDPLAN and PCI

Report portions of the MICROPASVER micro computer program are used for this purpose. The MICROPASVER program is identical to the PASVER mainframe program except the reports are displayed on the terminal and in hardcopy differently.

BUDPLAN is a budget planning report that provides the user with a 5-year estimate of the amount of money required to maintain a pavement section in excellent condition.

The PCI report lists sections in increasing order of PCI. Depending on the prioritization policy, projects can be sorted based on pavement surface type, pavement rank, traffic type and volume, PCI range, or a combination of factors (22:9).

In order to use the BUDPLAN report, the user must input repair costs for different ranges of PCIs as well as an inflation rate applicable for the 5-year period. The inflation rate data is the average inflation rate for the last 5 years. The repair costs vs PCI data come from a PASVER implementation manual written for Grissom Air Force Base, Indiana in 1985 by Eres Consultants. The costs represent SAC-wide unit Maintenance and Repair costs adjusted for inflation to 1988. The inflation rate used in this study will be the consumer price index (CPI) percentage change for 1986 and 1987. The inflation rate for 1986 is 6.1 percent and 5.8 percent for 1987 (17).

TABLE 4

PCC Pavement Rehabilitation Costs in \$/Sq Ft (27:105)

Pavement Condition Index				
0-2	21-40	41-60	61-80	81-100
\$9.95	\$3.73	\$1.87	\$0.62	\$0.13

A section repair cost differential of 15 percent (24:1) or more within the BUDPLAN reports using the AE derived PCI and the true PCI indicates an engineering significant difference. A cost differential this large adversely affects the ability of the pavement engineer to manage the airfield pavements at the network level. In addition, a prioritization differential of 4 positions based on the PCI report and the prioritization policy indicates a significant difference. Again, a difference this large can adversely affect the ability of the engineer to manage pavements at the network level.

The findings from the analyses, including their significance in terms of the research questions, is provided in Chapter IV and V of this research paper.

IV. Analysis

Introduction

The analysis in this section determines the accuracy of the AE sampling technique PCI with respect to the true PCI of the section. In addition, the AE sampling technique is compared with random sampling to identify which method provides a more representative sample of the condition of the pavement section. Finally, maintenance and repair costs are compared from the AE sampling technique data and the 100 percent survey data. Five Air Force bases participated in the study. Each base contributed at least two pavement sections to the study with a total of 13 sections being surveyed. All surveyed sections were either ranked as primary or secondary taxiways and aprons. The number of sample units within each section ranged from 6 to 42. Field data collection took approximately five months to complete with over 1.9 million square feet of pavement being surveyed.

The statistical and quantitative analysis of the pavement sections was structured around the research questions listed in Chapter I. This analysis was set up to identify network level management problems that would be encountered when using the alternative sampling method outlined in Chapter I.

Deviation of the Sample PCI vs the True PCI

The first question analyzed was: Is the absolute deviation between the average PCI obtained from the sampling method used in the AE Statement of Work and the true average PCI of a section significant?

Table 5 displays the absolute deviation between the sample mean PCI from the AE sampling technique and the true mean PCI from 100 percent sampling in each section surveyed. Nine out of the thirteen sections surveyed had deviations within plus or minus 5 PCI points. Of the four sections that had deviations greater than plus or minus 5 points, all had less than 15 sample units. In addition, three of the four sections used a sampling size of only two to determine the sample mean PCI.

Confidence Level Using the Alternative Sampling Rate

The second question analyzed was: What level of confidence is obtained from randomly selecting samples for each section using the AE sampling rate with the error interval given in AFR 93-5 of plus or minus 5 points?

Table 5 shows the confidence level for each section as a fraction of 100. The column with the Number of Sample Units Surveyed, is the AE survey sampling rate. In addition, the number of sample units and the known (population of 100 percent sample survey) standard deviation for each section is given. As an example for illustrative purposes,

TABLE 5

Mean PCI Absolute Deviation

Section Number	Number Sample Units	Number Sample Units Surveyed	True Mean PCI	Sample Mean PCI	PCI Deviation	Known Standard Deviation	Confidence Level	Number of Sample Units Required to Achieve 95% Confidence Level
19C	17	3	79	76	3	22.20	.15	15
21C	18	3	76	81	- 5	14.78	.23	13
24C	18	3	81	84	- 3	12.85	.26	12
T1A	12	2	44	34	10	13.16	.21	10
T2A	12	2	49	55	- 6	8.92	.31	8
A2B	42	8	41	42	- 1	10.03	.52	12
T7A	15	3	37	39	2	10.74	.31	10
AAB	8	2	55	52	3	8.21	.33	6
AAC	22	4	51	56	- 5	19.24	.20	17
AAF	13	3	65	73	- 8	19.41	.18	12
A32	20	3	78	79	- 1	5.01	.61	5
T33	20	3	79	81	- 2	5.55	.57	5
T36	6	2	52	58	- 6	12.98	.21	6

section 19C in Table 5 has a confidence level of .15. This represents the probability of randomly selecting 3 sample units and calculating a PCI within plus or minus 5 points of the true mean PCI of 79 using the known standard deviation of 22.20.

No section had a confidence level of greater than .61 or 61 percent. Ten out of the thirteen sections had confidence level of less than .35. In general, there is a low confidence of obtaining a PCI within 5 points of the true mean PCI when randomly selecting sample units according to the AE sampling rate.

Affect on Network Level Management

The third question analyzed was: Does the AE sampling rate adversely affect the pavement engineer's ability to correctly determine, at the network level, the maintenance and repair priorities and costs for airfield pavements?

The analysis of this question was broken into two phases. In phase one, only those sections with PCI deviations of more than 5 points were analyzed. In addition, an analysis is performed to determine the affect these four sections have on network level management of all the pavement sections included in this research. These analyses compared the maintenance and repair (M&R) cost differences of the AE sample survey and the 100 percent sample survey in both dollars and percent difference. Phase

two compared the pavement section maintenance and repair priorities of the AE sample survey and the 100 percent sample survey using the predicted PCIs for 1989.

To accomplish phase one, the budget planning report program in MICROPAYER was used to determine the maintenance and repair costs for 2 of the 4 sections with a PCI deviation greater than 5 points. However, the maintenance and repair costs for the other two sections, T-36 and AAF, could not be calculated in this manner. The program only works with those sections whose PCI will drop below a preselected minimum within the next 5 years. Neither sections T-36 nor AAF's PCI fell below this minimum within the required time frame when using the AE sample survey data. Therefore, another method for calculating the maintenance and repair costs for these two sections was devised. Using the Frequency report in MICROPAYER and the AE sample survey data, the year that sections T-36 and AAF reached the minimum PCI level was computed. In addition, the PCI for the same year was computed using the Frequency report and the 100 percent survey data (Figure 2). Repair costs for the pavement sections in question were then calculated using the predicted PCIs from both the AE sample survey and 100 percent sample survey data. This was accomplished using a straight line interpolation of the unit repair cost table, Table 4. When the four sections were compared together, there was a 10.9 percent difference

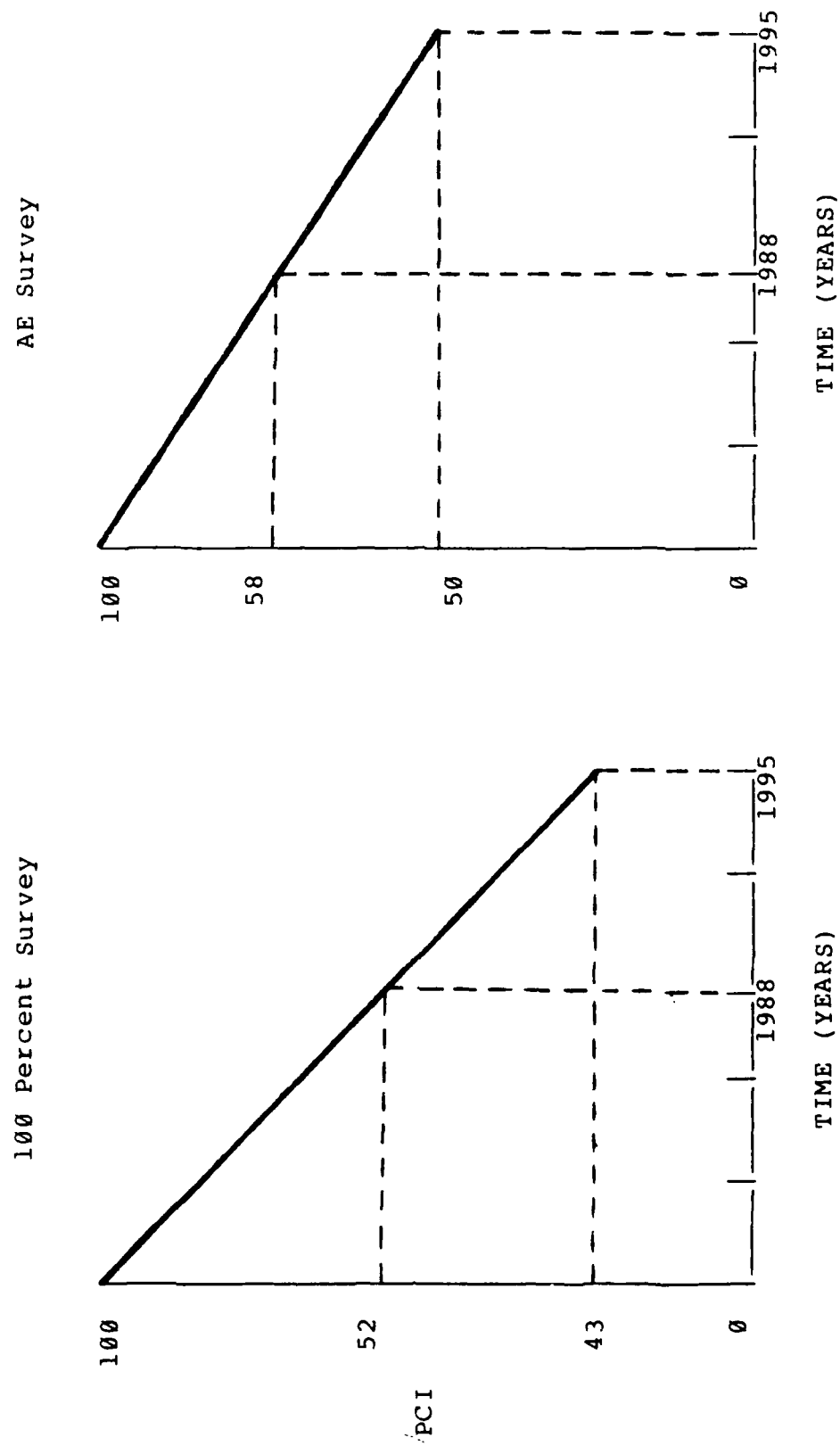


Figure 2. Section T-36 Predicted PCI

between the two totals which is below the maximum of 15 percent suggested for approximate square foot estimates (24:1). However, when the absolute differences of the two cost estimates in each section were added together, the absolute percent difference is 31.8 percent.

The impact these large percent cost differences have on network level management is shown in Table 7. As the table indicates, only four additional sections were identified for maintenance and repair by the budget planning program in MICROPAYER. The total absolute percent difference between the 100 percent survey cost estimate and the AE survey cost estimate dropped nearly 16 percentage points when compared to Table 6. In addition, the total percent difference decreased from 10.9 percent to 2.2 percent.

However, there is a problem with this analysis in that the predicted PCI used is a straight line extrapolation of two data points, original construction date and last inspection date (only inspection). Research has shown that the relationship between the PCI and the age of the pavement is actually nonlinear (Figure 3). This nonlinear relationship at present can only be plotted when there are a sufficient number of data points. Since the sections that were inspected had only two data points, original construction (PCI = 100) and one inspection, such a plot was not possible.

TABLE 6

Comparison of Budget Planning Reports
 100 Percent Survey vs AE Survey Rate
 (Section PCI deviations of more than 5 points)

Section Number/ Pavement Rank	100% Survey Predicted PCI	AE Survey Predicted PCI	Cost Using 100% Survey Predicted PCI (\$1000's)	Cost Using AE Survey Predicted PCI (\$1000's)	100% Survey AE Survey Difference	Section Percent Difference
T1A/P	42	32	351.26	476.22	124.96	35
T2A/P	47	53	290.11	227.14	62.97	21
T36/S	43	50	189.00	140.25	48.75	25
AAF/P	48	60	364.36	220.21	144.15	39
			Total Costs:	1194.73	1063.82	380.83

Total Percent Difference: 10.9

Total Absolute Percent Difference: 31.8

TABLE 7

Comparison of Budget Planning Reports
100 Percent Survey vs AE Survey Rate

Section Number/ Pavement Rank	100% Survey Predicted PCI	AE Survey Predicted PCI	Cost Using 100% Survey Predicted PCI (\$1000's)	Cost Using AE Survey Predicted PCI (\$1000's)	100% Survey AE Survey Difference	Section Percent Difference
T1A/P	42	32	351.26	476.22	124.96	35
T2A/P	47	53	290.11	227.14	62.97	21
T36/S	43	50	189.00	140.25	48.75	25
AAF/P	48	60	364.36	220.21	144.15	39
A2B/P	40	41	1436.75	1389.03	47.72	3
AAB/P	54	51	201.49	224.81	23.32	11
AAC/P	50	55	539.96	449.73	90.23	17
T7A/P	36	38	612.59	576.67	35.92	6
			Total Costs:	3621.16	3704.12	661.08
			Total Percent Difference: 2.2			
			Total Absolute Percent Difference: 15.9			

The predicted PCI for a section could be very unconservative. The actual percent difference between AE sample survey M&R costs and the 100 percent sample survey M&R costs may be significantly greater than this analysis indicates. This is especially true in the area where the predicted PCI drops 40 percent in 12 percent of the life of the pavement (see Figure 3). When a section reaches this point, more frequent surveys are required. Therefore, the Air Force practice of surveying every five years is inadequate for pavements in fair to poor condition.

In phase two, a comparison of the maintenance and repair priorities for the 100 percent sample survey and the AE sample survey was performed. These priorities are based on a predetermined maintenance and repair policy, Table 8. This policy is consistent with those found in the literature (22,6). A comparison of the maintenance and repair priorities is summarized in Table 9. It shows that the difference between the pavement section priorities for the two surveys was no more than 2 positions. It appears both survey techniques adequately prioritize pavement sections according to a predetermined maintenance and repair policy. However, only 13 sections were included in this study. The priorities may have deviated more significantly had the study included what would be the normal amount of sections found on an airfield, 100 or more.

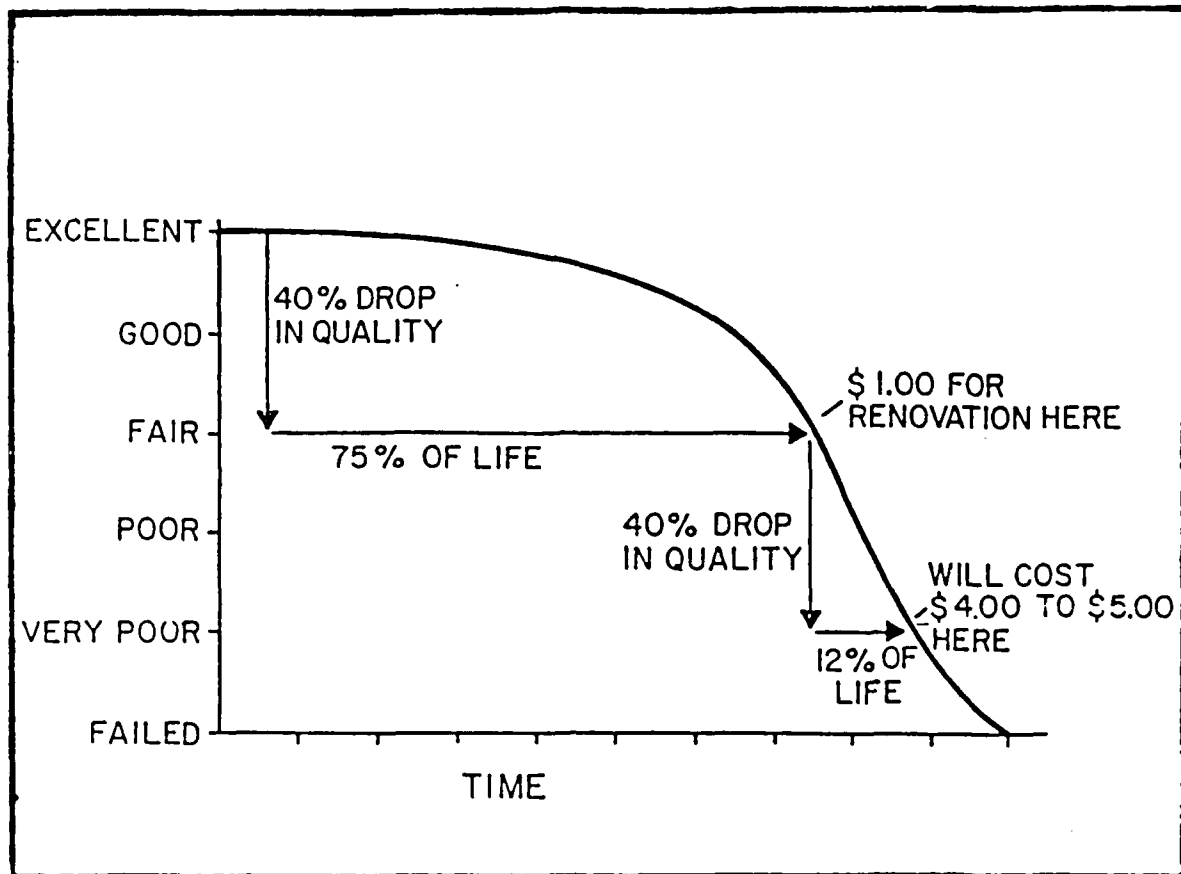


Figure 3. Pavement Deterioration vs Time (14:4)

Summary

The Analysis of the data gathered reveals both the statistical and quantitative differences between the AE sampling rate described in Chapter I and 100 percent sampling. Only a few significant differences were noted in the study. However, a possible problem with the quantitative analysis was described which could be masking a more significant difference than was indicated in the study. Chapter V provides the conclusions and recommendations of this report.

TABLE 8

Recommended Order of Precedence for Prioritization
(Poor Pavement Rehabilitated First) (22:21)

<u>PCI</u>	<u>Rank</u>	
	<u>Primary</u>	<u>Secondary</u>
Good 70 - 56	8	10
Fair 55 - 41	6	9
Poor 40 - 26	4	7
Very Poor 25 - 11	2	5
Failed 10 - 0	1	3

TABLE 9

Comparison of Maintenance and Repair Prioritization
Using Predicted 1989 PCI

<u>Section Number</u>	<u>Pavement Rank</u>	<u>100% Survey PCI / M&R Priority</u>	<u>AE Survey PCI / M&R Priority</u>
T7A	Primary	35 / 1	37 / 2
A2B	Primary	39 / 2	40 / 3
T1A	Primary	42 / 3	31 / 1
T2A	Primary	47 / 4	53 / 5
AAC	Primary	49 / 5	54 / 6
AAB	Primary	53 / 6	50 / 4
AAF	Primary	64 / 7	72 / 8
T36	Secondary	50 / 8	57 / 7
21C	Secondary	75 / 9	80 / 11
A32	Secondary	77 / 10	79 / 10
19C	Secondary	78 / 11	75 / 9
T33	Secondary	79 / 12	81 / 12
24C	Secondary	80 / 13	84 / 13

V. Summary, Conclusions, and Recommendations

Summary

The purpose of this study was to determine if the AE sampling technique (outlined in Chapter I) provides accurate data for computing the pavement condition index (PCI) of airfields.

AE consulting firms and the U.S. Army Construction and Research Laboratory (CERL) who have used the sampling technique claim it provides accurate data about the present condition of airfield pavements at a reasonable cost. The literature review reveals no evidence to either support or refute this claim for airfield pavements.

One hundred percent visual inspections are conducted on thirteen pavement sections at five Air Force bases. These five bases had pavement condition surveys accomplished using the sampling technique in question. The inspections are performed according to the survey procedures contained in the Air Force pavement evaluation regulation, AF 93-5.

Differences between the AE sample survey PCI and the 100 percent sample survey PCI are analyzed for each pavement section. In addition, estimated maintenance and repair costs in a section using the two sets of survey data are compared. Finally, differences in the maintenance and repair priorities for the thirteen pavement sections using the AE survey and the 100 percent survey data are analyzed.

Conclusions about the significance of the data obtained using the survey technique and the affect this data has on network level management are given in the following section. Following the conclusions, recommendations to ensure the AE sampling technique continues to provide accurate field data and areas for further research are given.

Conclusions

The Pavement Condition Index (PCI) obtained using the AE sampling technique is nearly as accurate as the PCI obtained surveying 100 percent of the pavement sections. Since network level analysis requires only an estimate of the true condition of the airfield pavements, the accuracy achieved using the AE sampling technique is adequate for this purpose. In addition, the samples selected for inspection by the AE sampling technique proved to be more representative of the condition of the pavement section than random sampling could likely achieve at the same sampling rate.

The AE sampling technique appears to provide an accurate preliminary estimate of the maintenance and repair costs for the airfield pavement network as a whole. However, when the pavement sections with PCI deviations greater than 5 points are compared separately or together there are considerable differences in the AE survey and the 100 percent survey data maintenance and repairs costs (Table 6). These differences can adversely affect network level

management of individual pavement sections. But when all thirteen pavement sections are analyzed as a group, large individual section budget differences do not have a great impact on network level management (Table 7). There is also a question about the assumption made concerning where on the deterioration curve (Figure 3) the pavement section is. The answer to this question is beyond the scope of this study. A discussion of this assumption and the possible affect it may have on this analysis if it were false is provided in the analysis chapter of this report. In general, the differences in the pavement repair budgets would be greater and, therefore, would adversely affect management of the airfield pavements at the network level. Either way more surveys are required to determine where exactly a pavement section is on the deterioration curve.

The question that arises from these conclusions is why does this sampling technique provide such accurate data when the sampling rate is so low? The reason is because the AE sampling technique uses the experience and engineering judgment of the inspector to select the most representative sample units within a section for inspection. An inspector who has performed numerous PCI surveys can use his experience to select the most representative samples from a section. He does this by noting the predominate distress types, their severity level, and density within the section and then selecting those sample units that mirror the condition of the

entire section. The amount of experience required to adequately perform this type of survey is beyond the scope of this study but needs to be addressed.

Another aspect that can help ease the difficulty in selecting the most representative samples within a section is the fact that many distress types dominate in certain geographical locations. This is especially true for environmentally induced distresses (e.g., freeze-thaw cycles causing durability cracking). This situation allows the inspector to look for distresses that are common to the geographical location in which he is surveying. In addition, sections tend to deteriorate at the same rate and have the same distress types. This occurs because the sample units within a section have the same characteristics that eventually lead to similar surface distresses. These characteristics can include pavement and base course thickness, time and type of construction, and type of traffic.

Finally, this sampling technique is much simpler to apply to pavement sections that are in the 80 to 100 PCI range (i.e., excellent rating). This is because pavement within this range has very few surface distresses. Therefore, it is much easier to select representative samples from a section in excellent condition than a section in fair to poor condition with many surface distresses. In addition, a pavement section in excellent condition will have a

low sample standard deviation. Thus fewer sample units will need to be inspected to achieve a high confidence level (e.g., 95 percent).

Although this research was comprehensive, the results obtained cannot be generalized across the entire Air Force. Since only taxiways and aprons constructed of portland cement concrete (PCC) were surveyed, results from this study are only applicable to these type traffic areas and surfaces. In addition, it is not possible to generalize how the AE sampling technique will perform in the future since the PCI survey experience of the AE firm plays such a large role.

Recommendations

It is recommended that the Air Force Engineering and Services Center (AFESC/DEMP) ensure future Statements of Work (SOW) for PAVER implementation require the contractor be highly experienced in airfield PCI surveys. The SOW should contain the following provision: The contractor shall employ engineers and engineering assistants to perform the PCI survey who have regularly conducted such surveys for the last three years (11). It is further recommended that the minimum number of sample units to be inspected be increased according to Table 10. This recommendation is given because three of the four pavement sections, whose AE survey PCI deviated by more than 5 points from the 100 percent survey PCI, used a sampling rate of two. In

addition, a sampling rate of one can not be used to calculate the standard deviation of a section, which is used to determine the number of units to be inspected for the next survey. Finally, it is recommended the contract inspectors perform 100 percent surveys on selected sections and use the methodology in this study to document contract compliance.

TABLE 10

Recommended Sampling Rate	
<u>No. of Sample Units in Section</u>	<u>Minimum No. of Units to be Inspected</u>
1	1
2-4	2
5-20	3
21-40	4
Over 40	10% rounded up

Topics for Further Research. The following are some topics for suggested future study:

1. Define the level of experience required to conduct airfield pavement condition surveys using the AE survey technique.

2. Using the methodology from this research, determine if the AE survey technique is applicable to runways and asphalt airfield pavements.

3. Determine the optimum number of sample units that should be inspected to balance accuracy versus cost to obtain data.

4. Determine the maintenance and repair prioritization policy that will most effectively use airfield maintenance and repair dollars.

5. Conduct a benefit/cost analysis of the PAVER pavement management system in the Air Force.

Appendix A: PCI Report

REPORT DATE: JUN/09/1099

AGENCY NUMBER: AFIT Air Force Base Ohio
AIR FORCE INSTITUTE OF TECHNOLOGY

BRANCH USE	SECTION NUM/RANK/SURF/AREA(SF)	LAST CONSTRUCT DATE	LAST INSPECTION DATE	PCI
TAXIWAY	19C/ S / PCC /	42420	JAN/15/1942 FEB/27/1988	79
TAXIWAY	21C/ S / PCC /	49050	JAN/15/1942 FEB/27/1988	76
TAXIWAY	24C/ S / PCC /	46500	JAN/15/1942 FEB/27/1988	81
TAXIWAY	A2B/ P / PCC /	513125	JUN/15/1942 MAR/18/1988	41
TAXIWAY	A32/ S / PCC /	73125	JUN/15/1941 MAY/13/1988	78
TAXIWAY	AAB/ P / PCC /	124375	JUL/15/1954 APR/09/1988	55
TAXIWAY	AAC/ P / PCC /	288750	JUL/15/1954 APR/09/1988	51
TAXIWAY	AAF/ P / PCC /	176875	JUL/15/1954 APR/09/1988	65
TAXIWAY	T1A/ P / PCC /	134375	JUN/15/1958 MAR/16/1988	44
TAXIWAY	T2A/ P / PCC /	135000	JUN/15/1958 MAR/16/1988	49
TAXIWAY	T33/ S / PCC /	75000	JUN/15/1941 MAY/13/1988	79
TAXIWAY	T36/ S / PCC /	75000	JUN/15/1954 MAY/13/1988	52
TAXIWAY	T1A/ P / PCC /	193125	JUN/15/1942 MAR/18/1988	37

Appendix B: Distress Data Report

DATE SURVEYED=MAR/16/1988 BRANCH/SECTION NUMBER=AE_SV/T2A

SECTION SIZE = 216 SLABS

TOTAL NUMBER OF SAMPLE UNITS - 12

ALLOWABLE ERROR WITH 95% CONFIDENCE = 5

SAMPLE UNIT ID = 04

SIZE OF SAMPLE = 18 SLABS

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
62 CORNER BREAK	LOW	1	5.56	4.3
62 CORNER BREAK	MEDIUM	2	11.11	16.0
62 CORNER BREAK	HIGH	1	5.56	14.0
65 JT SEAL DMG	MEDIUM	18	100.00	7.0
66 SMALL PATCH	LOW	2	11.11	1.3
67 LARGE PATCH	LOW	1	5.56	3.4
68 POPOUTS	N/A	18	100.00	22.3
74 JOINT SPALL	MEDIUM	4	22.22	15.0

PCI = 43

SAMPLE UNIT ID = 10

SIZE OF SAMPLE = 18 SLABS

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
64 DURABIL. CR	LOW	4	22.22	7.5
64 DURABIL. CR	MEDIUM	1	5.56	3.7
65 JT SEAL DMG	MEDIUM	18	100.00	7.0
66 SMALL PATCH	LOW	2	11.11	1.3
68 POPOUTS	N/A	18	100.00	22.3
75 CORNER SPALL	HIGH	1	5.56	5.2

PCI = 67

NUMBER OF RANDOM SAMPLE UNITS SURVEYED = 2

NUMBER OF ADDITIONAL SAMPLE UNITS SURVEYED = 0

PC⁺ OF SECTION = 55

RATING = FAIR

RECOMMEND EVERY SAMPLE UNIT BE SURVEYED.

STANDARD DEVIATION OF PCI BETWEEN RANDOM UNITS SURVEYED=17.0%

EXTRAPOLATED DISTRESS QUANTITIES FOR SECTION

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
62 CORNER BREAK	LOW	6	2.78	2.4
62 CORNER BREAK	MEDIUM	12	5.56	9.4
62 CORNER BREAK	HIGH	6	2.78	7.1
64 DURABIL. CR	LOW	24	11.11	3.7
64 DURABIL. CR	MEDIUM	6	2.78	2.4
65 JT SEAL DMG	MEDIUM	216	100.00	7.0
66 MALL PATCH	LOW	24	11.11	1.3
67 LARGE PATCH	LOW	6	2.78	2.0
68 POPOUTS	N/A	216	100.00	22.3
74 JOINT SPALL	MEDIUM	24	11.11	8.5
75 CORNER SPALL	HIGH	6	2.78	3.5

*** PERCENT OF DEDUCT VALUES BASED ON DISTRESS MECHANISM ***

LOAD RELATED DISTRESSES = 27.20 % DEDUCT VALUES.

CLIMATE/DURABILITY RELATED DISTRESSES = 18.82 % DEDUCT VALUES.

OTHER RELATED DISTRESSES = 53.98 % DEDUCT VALUES.

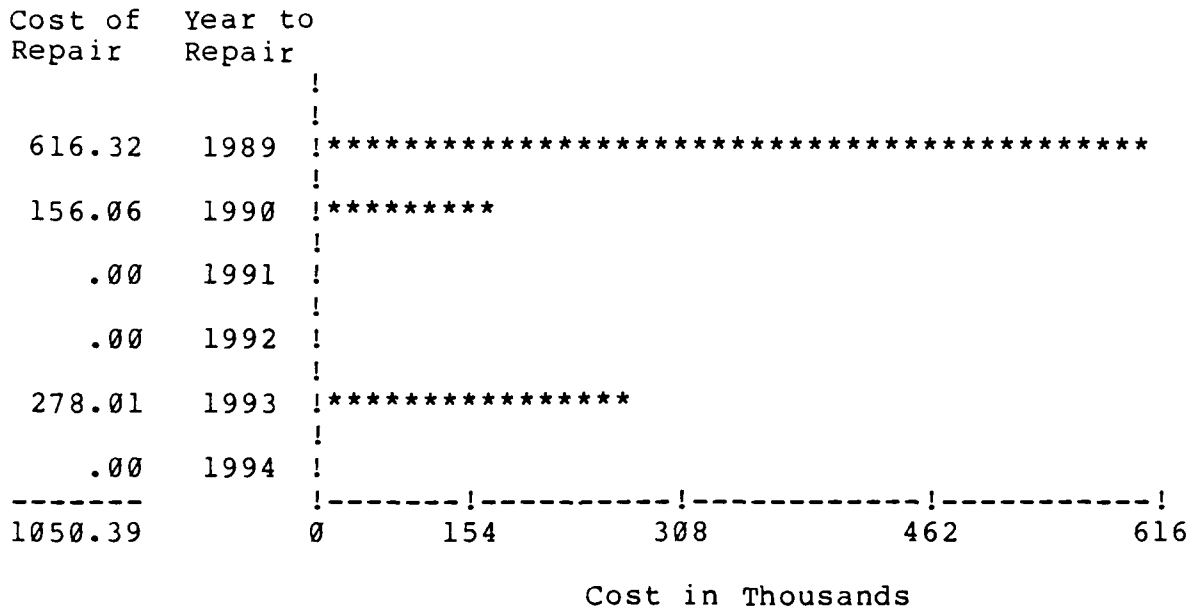
Appendix C: Budget Planning Report

Agency Name: AFIT Air Force Base Ohio
AIR FORCE INSTITUTE OF TECHNOLOGY

Report Date: JUN/13/1988

Branch Use : All
Pavement Rank : All
Surface Type : All
Zone : AF_1 AF_2 AF_3 AF_4 AF_5
Section Category : B
Last Construction Date: All
PCI : ALL
Inflation Rate : 6.00 %

Plot of Budget Planning Report



Section List of Budget Planning Report
(Costs in thousands of dollars)

Year to Repair	Branch Use	Section Num/Rank	Pred PCI	\$/SF	Section Area (SF)	Cost (\$1000's)
1989	TAXIWAY	T1A / P	43	2.52	134375	338.76
1989	TAXIWAY	T2A / P	48	2.06	135000	277.56
1990	TAXIWAY	T36 / S	49	1.96	75000	156.06
1993	TAXIWAY	AAF / P	60	1.25	176875	278.01

Summary of Data for the Budget Planning Report

Minimum PCI Table

Branch Use	Pavement Rank	Year of Repair					
		1989	1990	1991	1992	1993	1994
TAXIWAY	P	60	60	60	60	60	60
TAXIWAY	S	50	50	50	50	50	50

Unit Repair Cost Table
(Cost in \$/SF)

Surface Type	0-20	21-40	41-60	61-80	81-100
PCC	9.95	3.73	1.87	.62	.13

Appendix D: PCI Frequency Report 1988 and 1989

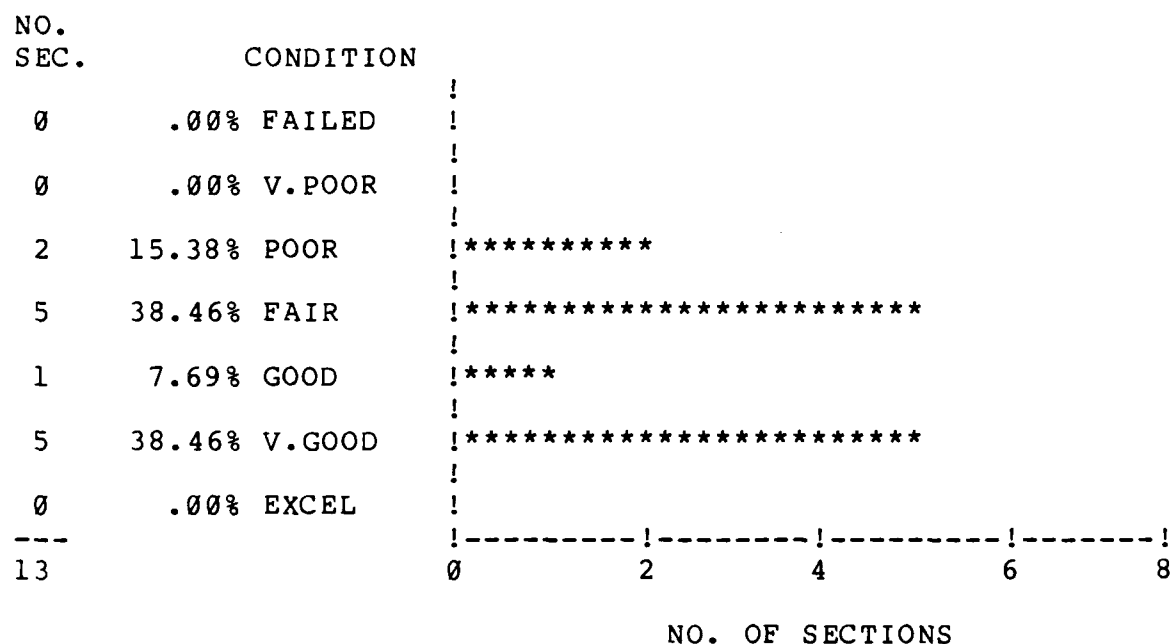
Agency Name: AFIT Air Force Base Ohio
AIR FORCE INSTITUTE OF TECHNOLOGY

Report Date: JUN/11/1988

Branch Use : All
Pavement Rank : All
Surface Type : All
Zone : AF_1 AF_2 AF_3 AF_4 AF_5
Section Category : All
Last Construction Date: All
PCI : ALL

PLOT OF PCI FREQUENCY REPORT

YEAR: JUN 1989



TOTAL NUMBER OF SECTION: 13
AVERAGE PCI : 59

SECTION LIST OF PCI FREQUENCY REPORT

YEAR: JUN 1989

BRANCH USE	SECTION NUM / RANK / SURF /	AREA	LAST INSPECTION	LAST PCI	PRED PCI
TAXIWAY	T7A / P / PCC/	193125	MAR/18/1988	37	35
TAXIWAY	A2B / P / PCC/	513125	MAR/18/1988	41	39
TAXIWAY	T1A / P / PCC/	134375	MAR/16/1988	44	42
TAXIWAY	T2A / P / PCC/	135000	MAR/16/1988	49	47
TAXIWAY	AAC / P / PCC/	288750	APR/09/1988	51	49
TAXIWAY	T36 / S / PCC/	75000	MAY/13/1988	52	50
TAXIWAY	AAB / P / PCC/	124375	APR/09/1988	55	53
TAXIWAY	AAF / P / PCC/	176875	APR/09/1988	65	65
TAXIWAY	21C / S / PCC/	49050	FEB/27/1988	76	75
TAXIWAY	A32 / S / PCC/	73125	MAY/13/1988	78	77
TAXIWAY	19C / S / PCC/	42420	FEB/27/1988	79	78
TAXIWAY	T33 / S / PCC/	75000	MAY/13/1988	79	79
TAXIWAY	24C / S / PCC/	46500	FEB/27/1988	81	80

PLOT OF PCI FREQUENCY REPORT

YEAR: JUN 1990

NO. SEC.	CONDITION	
0	.00% FAILED	!
0	.00% V. POOR	!
3	23.08% POOR	!*****
4	30.77% FAIR	!*****
1	7.69% GOOD	!*****
5	38.46% V. GOOD	!*****
0	.00% EXCEL	!
13		!-----!-----!-----!-----!
		0 2 4 6 8
		NO. OF SECTIONS

TOTAL NUMBER OF SECTION: 13
 AVERAGE PCI : 58

SECTION LIST OF PCI FREQUENCY REPORT

YEAR: JUN 1990

BRANCH USE	SECTION NUM /RANK/SURF/	AREA	LAST INSPECTION	LAST PCI	PRED PCI
-----	-----	-----	-----	-----	-----
TAXIWAY	T7A / P / PCC/	193125	MAR/18/1988	37	34
TAXIWAY	A2B / P / PCC/	513125	MAR/18/1988	41	38
TAXIWAY	T1A / P / PCC/	134375	MAR/16/1988	44	40
TAXIWAY	T2A / P / PCC/	135000	MAR/16/1988	49	45
TAXIWAY	AAC / P / PCC/	288750	APR/09/1988	51	48
TAXIWAY	T36 / S / PCC/	75000	MAY/13/1988	52	49
TAXIWAY	AAB / P / PCC/	124375	APR/09/1988	55	52
TAXIWAY	AAF / P / PCC/	176875	APR/09/1988	65	63
TAXIWAY	21C / S / PCC/	49050	FEB/27/1988	76	75
TAXIWAY	A32 / S / PCC/	73125	MAY/13/1988	78	77
TAXIWAY	19C / S / PCC/	42420	FEB/27/1988	79	78
TAXIWAY	T33 / S / PCC/	75000	MAY/13/1988	79	78
TAXIWAY	24C / S / PCC/	46500	FEB/27/1988	81	80

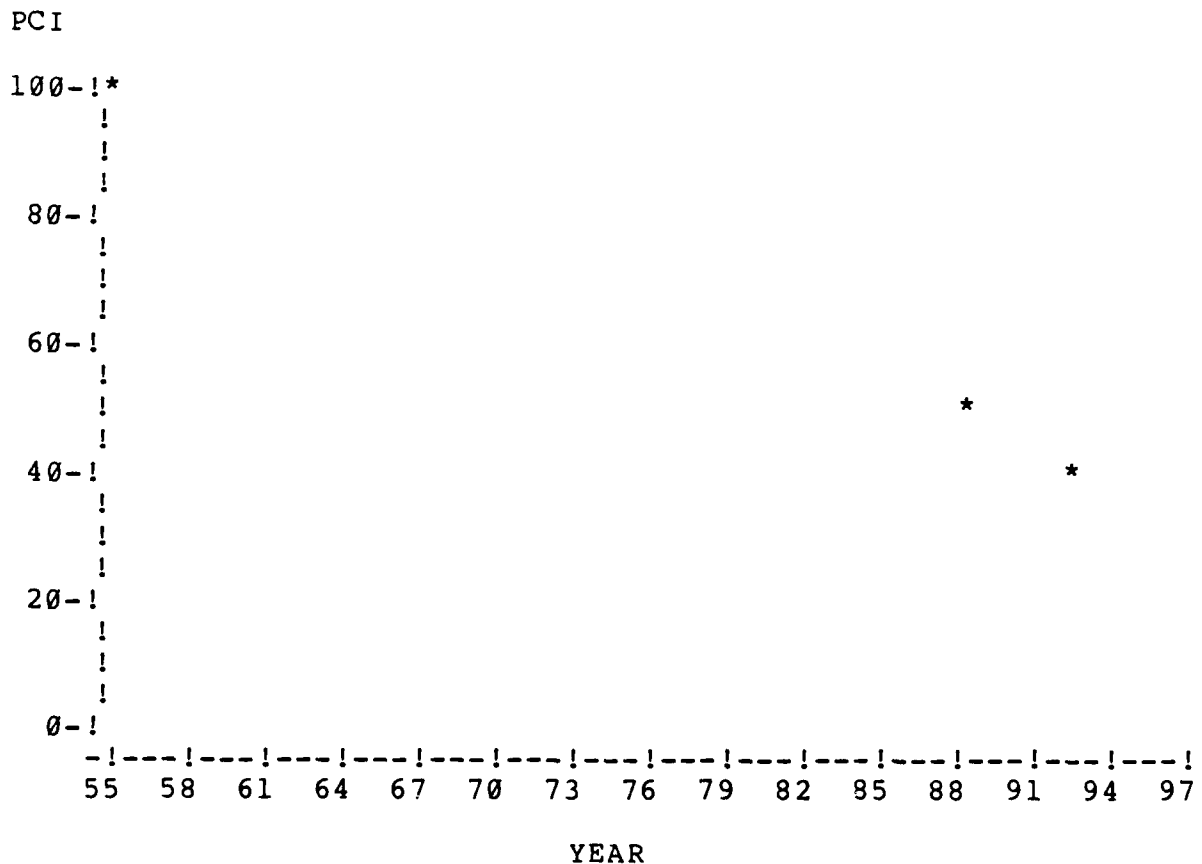
Appendix E: Condition History

AGENCY NAME: AFIT Air Force Base Ohio
AIR FORCE INSTITUTE OF TECHNOLOGY

REPORT DATE: JUN/13/1988

BRANCH NAME: AIR FORCE SURVEYS
BRANCH USE: TXIWAY
SECTION NUMBER: AAC
PAVEMENT RANK: PRIMARY
SURFACE TYPE: PCC

	DATE	PCI
	----	---
CONST/OVERLAY	JUL/15/1954	100
INSPECTION	APR/09/1988	51
PREDICTION	APR/01/1993	44



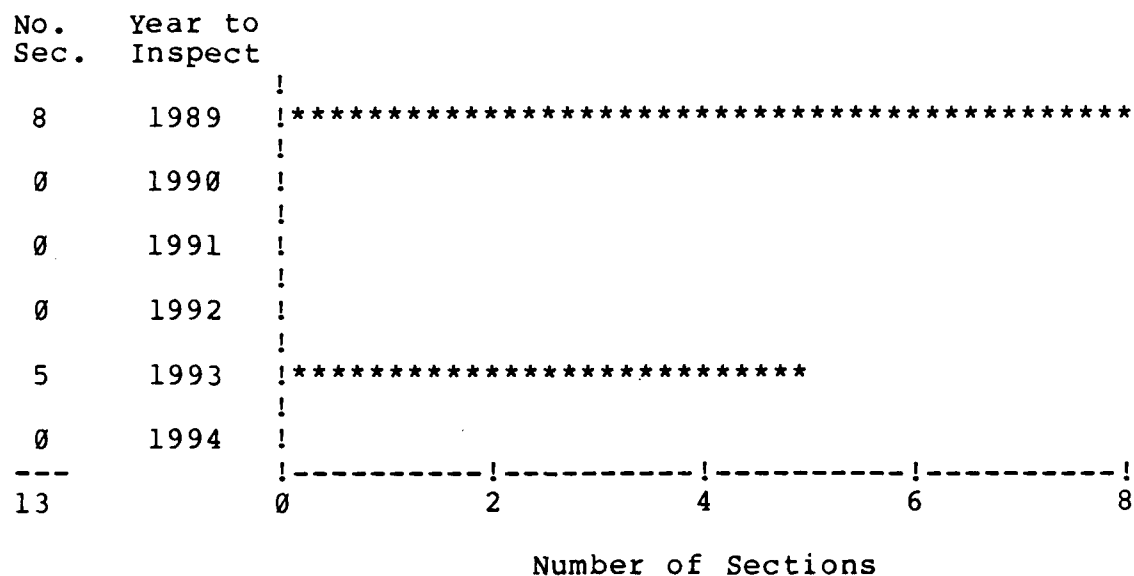
Appendix F: Inspection Schedule Report

Agency Name: AFIT Air Force Base Ohio
AIR FORCE INSTITUTE OF TECHNOLOGY

Report Date: JUN/13/1988

Branch Use : All
Pavement Rank : All
Surface Type : All
Zone : AF_1 AF_2 AF_3 AF_4 AF_5
Section Category : All
Last Construction Date: All
PCI : ALL

Plot of Inspection Schedule Report



Total Number of Sections to Inspect : 13
Total Number of Sections Not Needing Inspection: 0

Section List of Inspection Schedule Report

Year to Inspect	Branch		Section			
	Num	Use	Num	Rank	Surf	Area(SF)
1989	AF_SV	TAXIWAY	A2B	P	PCC	513125
1989	AF_SV	TAXIWAY	AAB	P	PCC	124375
1989	AF_SV	TAXIWAY	AAC	P	PCC	288750
1989	AF_SV	TAXIWAY	AAF	P	PCC	176875
1989	AF_SV	TAXIWAY	T1A	P	PCC	134375
1989	AF_SV	TAXIWAY	T2A	P	PCC	135000
1989	AF_SV	TAXIWAY	T36	S	PCC	75000
1989	AF_SV	TAXIWAY	T7A	P	PCC	193125
1993	AF_SV	TAXIWAY	19C	S	PCC	42420
1993	AF_SV	TAXIWAY	21C	S	PCC	49050
1993	AF_SV	TAXIWAY	24C	S	PCC	46500
1993	AF_SV	TAXIWAY	A32	S	PCC	73125
1993	AF_SV	TAXIWAY	T33	S	PCC	75000

Summary of Data for the Inspection Schedule Report

Minimum PCI Table

Branch Use	Pavement Rank	Min PCI
TAXIWAY	P	70
TAXIWAY	S	60

Number of Years Between Inspections Table

Rate of Deterioration (pts/yr)	Years Between Inspections
> 9	1
6 - 9	1
2 - 5	2
< 2	5

[illegible]

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VITA

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[REDACTED]
[REDACTED]

He earned a Bachelor of Science degree in Civil Engineering from California State Polytechnic University at Pomona in June 1982. On 1 July 1983 he was commissioned into the United States Air Force. His first duty station was the 27th Civil Engineering Squadron at Cannon Air Force Base in New Mexico. During his tour there, he served as the Chief of Environmental and Contract Planning and later as the Chief of Readiness. In addition, prior to his assignment to the Graduate Engineering Management program in 1987, he became a registered professional engineer with the state of California.

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REPORT DOCUMENTATION PAGE

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UNCLASSIFIED

Abstract

The purpose of this study is to investigate and quantify the accuracy of the pavement condition data obtained sampling 10 to 20 percent of the airfield pavement section based on the judgement of the pavement engineer. This research was limited to portland cement concrete sections. In order to solve the primary research objective, three research questions will be answered. (1) Is the mean Pavement Condition Index (PCI) using this sampling technique significantly different than the true PCI determined by surveying 100 percent of the airfield pavement section? (2) Is the PCI obtained using this sampling technique more representative of the section's condition than random sampling would achieve? (3) Does this sampling technique adversely affect the ability of an engineer to manage airfield pavements at the network level?

To answer the research questions, all of the sample units in thirteen sections at five Air Force bases are surveyed. All of these bases were previously surveyed according to the sampling technique in question. The 100 percent survey PCI and the sampling technique PCI for each section are compared.

The research found that the sampling technique and the sampling rate in question provide an accurate PCI for network level analysis of airfield pavements. The analysis indicates the lower sampling rate provides a PCI almost as accurate as 100 percent sampling. In addition, the sampling technique selected sample units that are more representative of the pavement section condition than random sampling at the same sampling rate. Finally, the investigation determined that this sampling technique provides the engineer with reliable data about the condition of the airfield pavements. This, in turn, gives the engineer confidence that his network level management strategies are appropriate.

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